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Arterial traffic signal optimization: A person-based approach

Eleni Christofa [a,*], Konstantinos Ampountolas [b], Alexander Skabardonis [c]

[a] *Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA 01003, United States*
[b] *School of Engineering, University of Glasgow, Glasgow G12 8LT, United Kingdom*
[c] *Institute of Transportation Studies, University of California, Berkeley, CA 94720, United States*

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ABSTRACT

This paper presents a real-time signal control system that optimizes signal settings based on minimization of person delay on arterials. The system's underlying mixed integer linear program minimizes person delay by explicitly accounting for the passenger occupancy of autos and transit vehicles. This way it can provide signal priority to transit vehicles in an efficient way even when they travel in conflicting directions. Furthermore, it recognizes the importance of schedule adherence for reliable transit operations and accounts for it by assigning an additional weighting factor on transit delays. This introduces another criterion for resolving the issue of assigning priority to conflicting transit routes. At the same time, the system maintains auto vehicle progression by introducing the appropriate delays associated with interruptions of platoons. In addition to the fact that it utilizes readily available technologies to obtain the inputs for the optimization, the system's feasibility in real-world settings is enhanced by its low computation time. The proposed signal control system is tested on a four-intersection segment of San Pablo Avenue arterial located in Berkeley, California. The findings show the system's capability to outperform pretimed (i.e., fixed-time) optimal signal settings by reducing total person delay. They have also demonstrated its success in reducing bus person delay by efficiently providing priority to transit vehicles even when they travel in conflicting directions.

1. Introduction

With the continuous growth of population and car ownership and the limited funds available, there is an imperative need to design and manage multimodal transportation systems more efficiently while improving the use of existing infrastructure. With traffic signal control systems already widely deployed in urban street networks, one of the most cost-effective ways to improve efficiency and sustainability of urban transportation systems is to develop signal control strategies that enhance person mobility. This can be achieved with the development of signal control strategies that in addition to resolving conflicts between vehicles, give preferential treatment to high occupancy transit vehicles while accounting for the overall traffic conditions in the network.

Several advanced real-time signal control systems have incorporated transit signal priority strategies in their algorithms in order to manage multimodal systems more efficiently. However, very few systems optimize signal settings by explicitly minimizing person delay in a network. On the contrary, they usually minimize vehicle delays (Cornwell et al., 1986;

* Corresponding author. Tel.: +1 (413) 577 3016.
E-mail addresses: christofa@ecs.umass.edu (E. Christofa), konstantinos.ampountolas@glasgow.ac.uk (K. Ampountolas), skabardonis@ce.berkeley.edu (A. Skabardonis).

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Hunt et al., 1982; Bretherton et al., 2002) and provide priority based on rules that are not directly included in the optimization process (Conrad et al., 1998; Diakaki et al., 2003) or pre-select a subset of transit vehicles to apply their priority strategies (Mauro and Taranto, 1989; Henry and Farges, 1994). Some systems have optimized signal settings by minimizing some weighted combination of passenger delay, car delay, bus delay, and bus schedule delay (Chang et al., 1996; Vasudevan, 2005; Li et al., 2008; Stevanovic et al., 2008; Ma et al., 2013a) and others by reducing bus travel time or passenger waiting time at the downstream bus stop while minimizing the impact these priority strategies have on the rest of the traffic (Ma et al., 2013b; Lin et al., 2013; Zeng et al., 2014).

Recently, several real-time signal control systems that take advantage of data from Connected Vehicles (CV) (i.e., vehicle-to-vehicle and vehicle-to-infrastructure communications) have been developed. These systems have attempted to optimize signal timings for signalized arterials based on weighted functions of delays for all users, accounting for priority requests of buses and/or pedestrians and maintaining coordination of traffic signals. However, they either require high penetration of probe vehicles (for different modes) to be successful and in some cases have high computation times that constrain their applicability in real-world settings (He et al., 2012) or assume a background offline optimized plan (He et al., 2014).

A person-based traffic-responsive signal control system for isolated intersections was recently proposed in Christofa and Skabardonis (2011) and Christofa et al. (2013). This system minimizes person delay by explicitly accounting for the passenger occupancy of autos and transit vehicles. This results in provision of signal priority to transit vehicles and introduces an efficient way for resolving the issue of priority assignment when transit vehicles travel in conflicting directions. The system uses real-time information that can be obtained form currently deployable surveillance and communication technologies (i.e., vehicle detectors, Automated Vehicle Location (AVL) and Automated Passenger Counter (APC) systems). A few other systems that minimize person delay at signalized intersections and arterials have been proposed since. Christofa et al. (2013) developed a real-time signal control system similar to the one Christofa et al. (2013) developed that minimizes total person delay at isolated intersections under the assumption of CV data availability. Availability of CV data allowed them to estimate vehicle delays individually avoiding second order terms in their mathematical program. However, this system was restricted to isolated intersections, and did not account for transit schedule adherence in the objective function. Another real-time signal control system that minimizes person delay for all users at consecutive signalized intersections with the use of CV data was also recently proposed (Hu et al., 2015). The system was tested only for a two-intersection arterial segment and under the assumption of a maximum of one bus priority provision per cycle. Under its current form, the system cannot be used for cases with multiple conflicting bus lines and multiple priority requests, while the current computation time could prohibit its implementation in real-world signalized arterials with multiple intersections.

Overall, most existing systems ignore the case of multiple priority requests (i.e., multiple transit lines) basing their decisions on pre-selected priority for the buses or treating them on a first come first served basis. Therefore, they lack an efficient way of assigning priority to transit vehicles especially when they travel on conflicting routes. Furthermore, they often ignore the importance of transit schedule adherence in providing priority, which in some cases can cause further disruptions to the transit system. Finally, recent studies that have addressed some of those issues can either not be implemented in real-world settings given their existing data requirements and high computation times or are restricted to optimize signal settings at isolated intersections.

This paper presents an extension of the traffic responsive signal control system previously published by Christofa and Skabardonis (2011) and Christofa et al. (2013). The system is extended to arterials that are characterized by multiple transit lines traveling in conflicting directions and platooned vehicle arrivals. In addition to accounting for auto vehicle progression, by assigning the appropriate delays for interrupting the platoons, the system recognizes the importance of schedule adherence for reliable transit operations. Therefore, it introduces an additional weighting factor that reflects how early or late a transit vehicle is when arriving at an intersection and assigns priority accordingly facilitating priority assignment decisions when transit vehicles travel in conflicting directions. Another advantage of the system is its low computation time due to its mathematical formulation and pairwise signal optimization as well as the use of readily available data, both of which are promising for real-time applications.

The proposed signal control system is tested on a four-intersection segment of San Pablo Avenue arterial located in Berkeley, California, and the results are compared against the performance of optimal fixed-time signal settings obtained from TRANSYT-7F (Hale, 2009). TRANSYT-7F is a state-of-the-art offline traffic signal optimization software that is extensively used in the U.S. and Europe. It is flexible in that it allows the user to choose the objective function from a variety of available functions. In addition, the user can choose from two optimization techniques (hill-climb and genetic algorithm), and the software is able to optimize all signal settings (i.e., cycle length, phasing sequence, splits, and offsets). Finally, it can handle both pretimed and actuated control.

The rest of the paper is organized as follows: Section 2 is dedicated to the proposed person-based optimization approach and the underlying mathematical model. In Section 3, a case study for a four-intersection arterial in Berkeley, California is introduced. Section 4 presents the performance and effectiveness of the proposed person-based approach under deterministic and stochastic arrivals. Finally, Section 5 discusses the findings of this work and outlines areas for future research.